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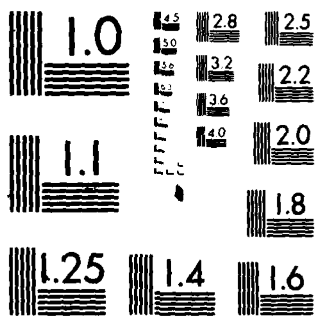

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by

Jerzy Michalczewski

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SYNOPTIC CONDITIONS OF THE OCCURRENCE OF SEA BREEZES ON THE POLISH COAST OF THE BALTIC SEA

Jerzy Michalczewski

In recent years sea breezes have been considered quite often in the meteorological literature, mainly, however, from the climatological or dynamic point of view [1,4,8]. They have been discussed very seldom from the synoptic viewpoint; Fisher [3] studied them for a sector of the Atlantic coast of the United States of America, and Estoque [2] carried out theoretical work of the mechanism in connection with a synoptic situation.

As far as the Polish sector of the Baltic coastline is concerned, there is lack of more serious work, apart from older studies of Koschmieder and his students [5,6]. The author made a contribution to this work [7] which was an attempt to investigate the sea breeze on the basis of synoptic analysis. In view of considerable interest evoked by that attempt, the author yielded to the temptation to make a more systematic analysis of the problem, based on more material of 141 cases in the years 1954-60 and applying the same investigation method as before. The analysis was limited this time to the coastal sector between Dziwnowo and Rozewie, having more or less a rectilinear course. We omitted Zalew Szczecinski and Gdansk Bay. This selection was dictated by our desire to discover some typical interrelations, which are not disturbed by the configuration of the coast.

When considering the sea breeze against the backgrou[illegible] a macrocirculatory system, it is necessary in advance to eli[illegible]e those cases in which the wind gradient itself causes the inflow of the sea air over the land. Under those conditions, even if the breeze appears, it is entirely unsuitable for studies by synoptic methods and disappears in the general air movement. What remains then for analysis are those cases in which the primary circulation (connected with baric systems) brings the air from land over the sea, and the breeze appears as a separate circulatory system. We

can distinguish four general cases:

1) the coast is in the quiet (silence) zone (high baric center)
2) the inflow of air is from the southwestern quadrant (up to about 250°)
3) the air flows from the eastern direction
4) the air comes from the southern direction. This fourth case is particularly interesting, since then the breeze flows against the wind from the land.

1. The first case may be illustrated by the breeze on May 30, 1959 (Figure 1). On that day the coast remained near the axis of the high pressure system covering the Baltic Sea. The lines of currents on the map at 0700 hours show the spreading of air from the area of Pomorze outwards, and along the coast the winds are directed over the sea, giving the picture of a land breeze. In this situation, as the land began to warm up, the wind changed its direction and at 0800 hours the breeze went over the land. The map "b" shows its range at 1300 hours. However, the whole baric system also underwent a transformation so that the general outflow of air began to coincide to a large degree with the direction of the breeze. In this situation, it became impossible to follow the course of the breeze.

2. The case from June 24, 1958 (Figure 2) may serve as an example of breeze formation with wind blowing from the direction of about 230°. On that day Wybrzerze (the coast) was located in the zone of western wind on the northern side of the high pressure ridge. The current lines on the map at 0700 hours show a "sucking" (vacuuming) action of the Baltic, expressed by a deviation of the current lines towards the sea. The breeze started over the land at 1000 hours and at 1300 hours, the map shows its range in the form of converging lines. Both air streams form an angle of 90°. However, near the evening the situation underwent a change and on the map at 2100 hours the winds blow rather chaotically, acquiring a distinct local character.

3. The flow of air from the eastern direction provides the largest number of cases of breeze, because of the prevailing weather

conditions, i.e., little clouding. An example of such a situation was provided by the day May 10, 1959 (Figure 3). The area of high pressure with center over Finland covered large regions of northern, central and eastern Europe, causing the movement of air masses in Poland from the east to the west (as seen on the map at 0700 hours). At 0800 hours, the breeze appeared over the land and at 1300 hours, it covered the relatively narrow coastal belt. It is characteristic that the sea breeze remained the longest time on the western sector of the coast since even the map at 2100 hours shows part of the coast still under its influence.

4. Air flows from the southern quarter provide the most interesting cases of breezes for now the inflow of sea air goes "against the current" of the gradient wind. In these cases one can observe a distinct dependence of the appearance of breeze on the wind velocity from the land. Inasmuch as in cases similar to previous breezes the appearance of breeze occurs at about 0800 hours in the morning for at the southern flow the breeze starts over the land at midday or even only in the afternoon. It happens also that in these situations, the breeze does not reach the land at all.

An example of the formation of breeze for winds from the SW direction is provided by the case of June 16, 1958 (Figure 4). A system of high pressure with center over Latvia caused a flow of air over Poland during the whole day from the southeast with velocity of about 2-3 m/sec. In this situation, the breeze had to move against the gradient wind which delayed its starting over land until midday. At 1300 hours it has the largest range in the eastern part of the coast and the shortest range in the western part. As the sunshine covered areas decreased, the gradient wind pushed back the breeze again from the land and the map at 2100 hours already does not show any traces of it.

Cases when the same direction of air inflow is maintained for the whole day are not frequent. As a rule, the general baric situation undergoes changes and with it, the conditions under which the

breeze form also change. As an example, we could take here the case of July 23, 1959. The transformation and movement of anticyclonic system with a center over the Ukraine changed the direction of air movement at the coast from SE in morning hours to SW in the evening and this favored maintaining the breeze.

The described case is one of the simplest. In other investigated situations the changes were of a more radical nature and caused far reaching modifications of the course of breeze phenomena. In each case, however, one could distinguish at least temporarily any one of the above described model situations.

In the course of the analysis of meteorological maps, attention was drawn to the large regularity of relations between, for instance, the direction of breeze wind and direction of general air movement, or between their velocities (Figures 5a and 5b). We tried to calculate these relations, assuming that there exists a functional dependence between these phenomena of the form

$$\bar{K}_m = f(\bar{K})_l \qquad \text{and} \qquad \bar{v}_m = f(\bar{v})_l$$

From the material at our disposal, we rejected those cases in which the course of breeze was disturbed during the day by a change in steering circulation. For the remaining cases we compared average directions and velocities of the wind from the land at 0700 hours and of wind from the sea at 1300 hours. These values demonstrated the validity of the relation:

$$\bar{K}_m = -\frac{1}{2}\bar{K} + 445$$

where: $\bar{K}_m$ - average direction of sea breeze in degrees (calculated from N through E, as accepted in meteorology)

K_l - average direction of the land wind in degrees (here we considered the real wind, not the geostrophic one).

For the velocity, we obtained the relation

$$\bar{v}_m = \frac{4}{5}\bar{v}_l + 1$$

where: $\bar{v}_m$ - average velocity of sea breeze in m/sec
v_1 - average velocity of the land wind in m/sec.

Synoptic maps allow one to determine the range of the breeze into the depth of the mainland [7]. However, it remains still an open question at what distance from the coast this breeze originates in the Baltic. We made an attempt to clarify this problem on July 21, 1962 by checking the state of the surface of the sea from an airplane. At the place of origin of the breeze, we expected to find a smooth area, not wrinkled by water waves. For when the gradient wind blows from land over the sea, and the breeze blows from the sea to the land, there should exist a location over the water where the action of both winds cancels and silence reigns. From this spot the winds should diverge in opposite directions.

Such a situation should be observed most clearly when the wind blows from the land perpendicular to the coastline. If there is such a line of divergence at the sea, then water along this line will not be wrinkled by wind waves, which, however, should appear on both its sides, running from one side towards the land and from the other side towards the sea. We attempted to find such a place.

On July 21, 1962, the weather was sunny (2/8 Cu, wind 170° - 2 m/sec, the air near the ground layer somewhat hazy). At 10:30 hours, we started and flew at an altitude of 50 m where we turned over the sea. The sea surface was covered with small wavelets on the background of long, flat and low waves coming from the open sea. At the distance of about 4 km from the coast, we noticed elongated mirrors of smooth water which did not form a uniform belt, but continued more or less parallel to the coastline in the form of separate broken up areas overlapping each other.

The waves in this zone shaped themselves in the way expected from theoretical considerations: in the area of smooth lustrous water one could see only long and flat waves coming from the open sea. On the other hand, on both sides of this area the wind wrinkled the water into small scales, which become larger wind waves gradually

as the distance increased, and they ran in opposite directions: the waves from the land side were moving towards it. In this way, we gained confirmation of our assumptions.

The sea breeze is a phenomenon of interest not only of sailors and bioclimatologists, but also to glider pilots. Parczewski [8] advises glider pilots to make their flights in the breeze zone. According to information reaching this author, such attempts were made by pilots but they ended in failure. The glider pilots starting from the gliding airfields located on land at some distance from the coast encountered the zone of descending currents, which they were not able to overcome in order to reach cumulus clouds related with the breeze and were visible along the coast. A certain explanation of this phenomenon may be found in Figures 1b and 6. It is clearly seen on those maps that ahead of the "breeze front" the current lines show an anticyclonic curvature in a rather broad zone, reaching a width of 30 km. This curvature may be considered as an indication that the air over this area spreads out and settles down, hence a glider indeed should encounter descending movements.

The results of this work suggest the following conclusions:

1. The studies conducted showed a dependence of the sea breeze at the coast on the existing macrocirculatory systems. In the case of winds from eastern or western directions, the breeze appears relatively early in the morning or before noon. On the other hand, for strong southern winds it either does not go over the land at all, or appears only in the afternoon hours in the form of a "breeze front" discovered byKoschmieder.

2. The range of breeze over the land depends also on the macrocirculation. In the case of winds from western directions, it may reach as far as 70 km inside the country along the valley of Odra, and up to 30 km in the eastern part of Pojezierze Pomorskie. With eastern winds the range may be of the order of more than 10 km. But the smallest range occurs for breeze with winds from southern

directions: from a few tens of meters to several kilometers, and not over the whole coast. For sufficiently strong winds from the land ($v \geqslant 5$ m/sec), the breeze may not reach the coast at all.

3. The place of origin of the breeze in the sea lies from several hundred meters to several kilometers from the coast. This conclusion is based on a few visual observations of the author and on calculations of Estoque, and still requires confirmation by measurements. The whole phenomenon should be studied more thoroughly under different synoptic situations.

4. In many cases the lines of air currents over the land ahead of the breeze front showed an anticyclonic curvature. This fact is explained by the existence in this zone of descending currents, confirmed by glider pilots. The investigated situations at the E and SE air flow have not shown such curvature.

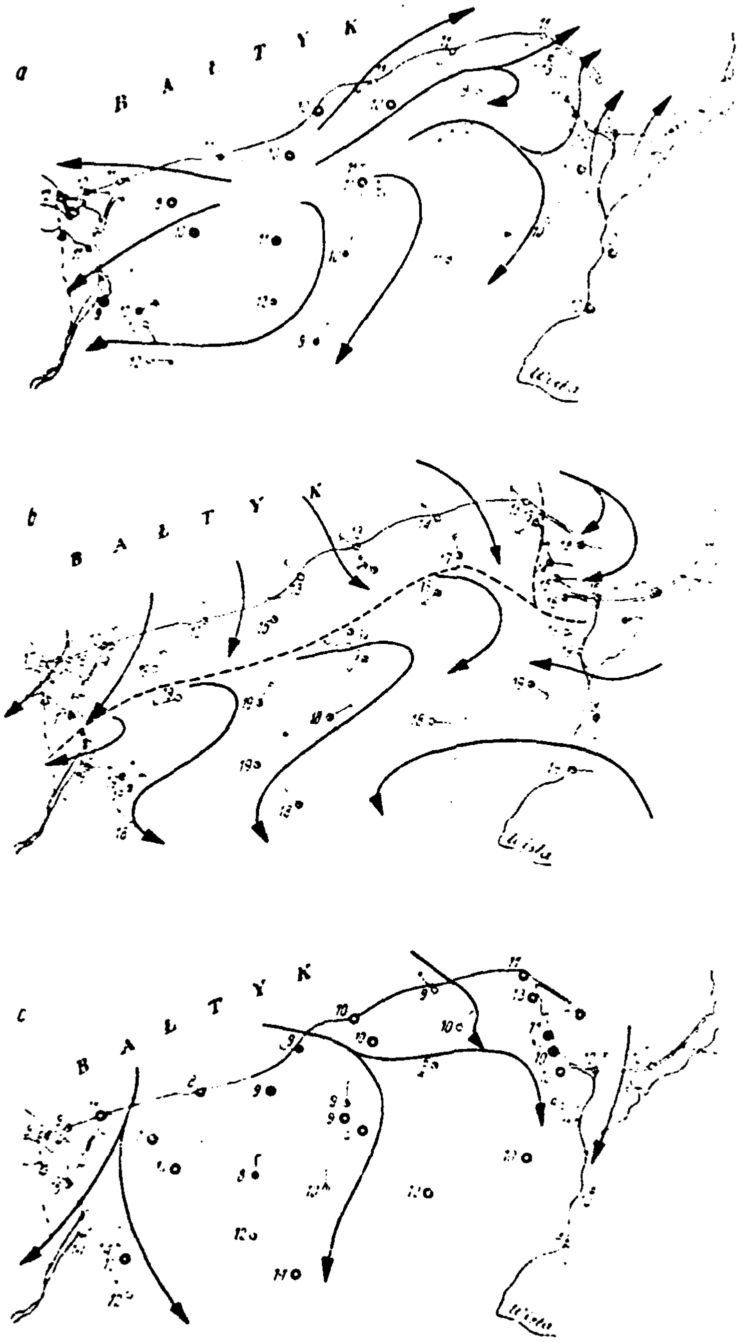

Figure 1. An example of breeze on May 30, 1959
a) distribution of air currents at 0700
b) distribution of air currents at 1300
c) distribution of air currents at 2100

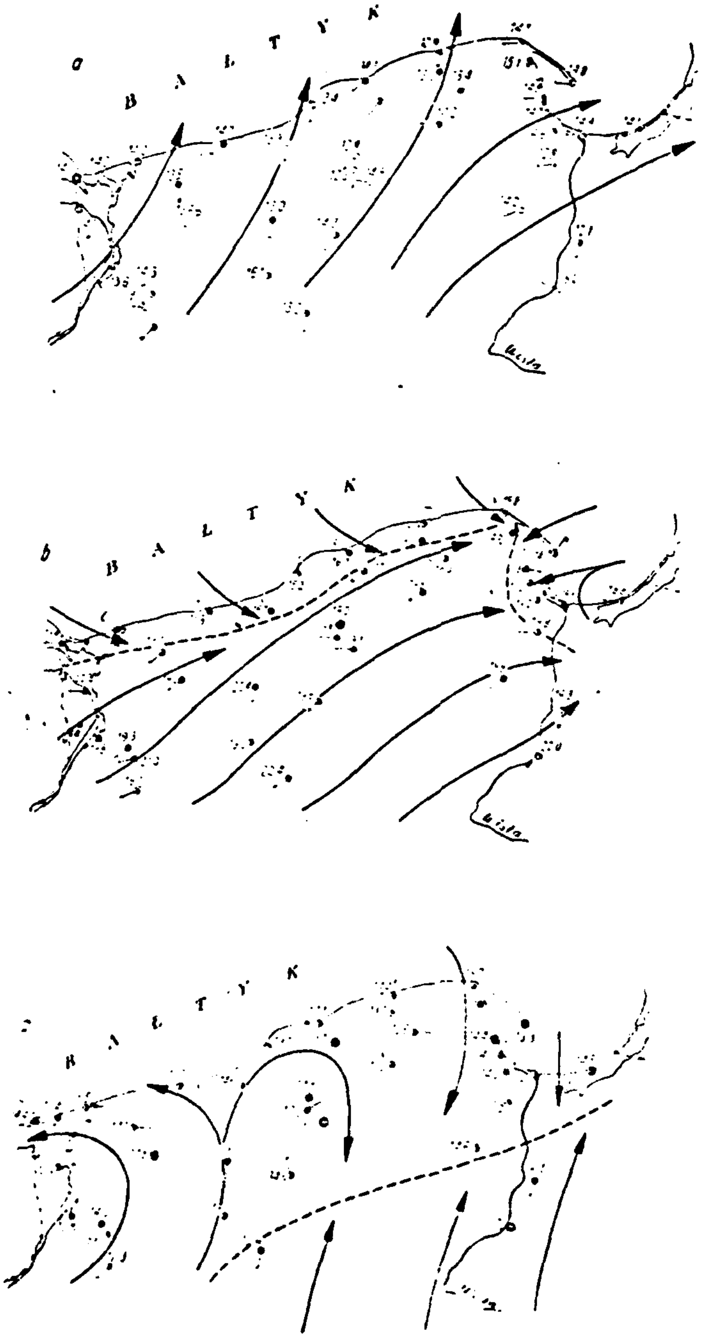

Figure 2. An example of breeze on June 24, 1958
a) distribution of air currents at 0700
b) distribution of air currents at 1300
c) distribution of air currents at 2100

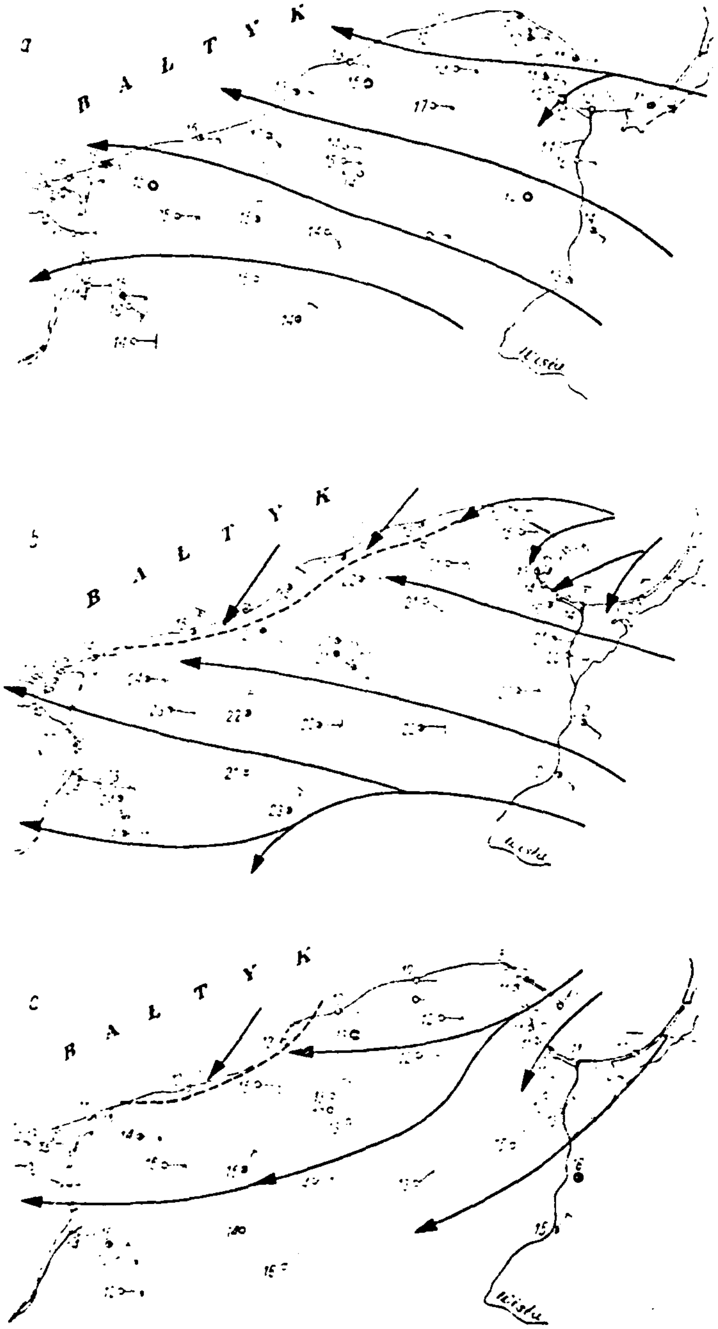

Figure 3. An example of breeze on May 10, 1959
a) distribution of air currents at 0700
b) distribution of air currents at 1300
c) distribution of air currents at 2100

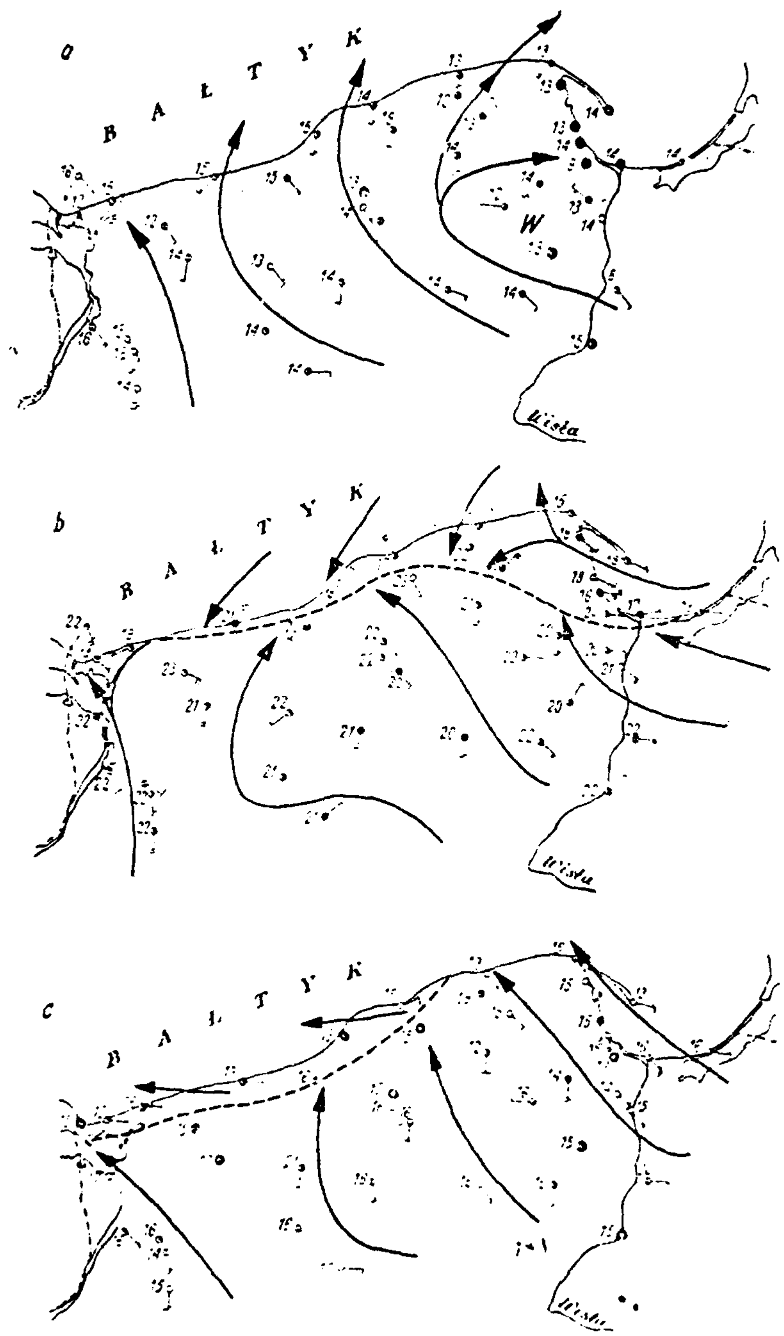

Figure 4. An example of breeze on June 16, 1958
a) distribution of air currents at 0700
b) distribution of air currents at 1300
c) distribution of air currents at 2100

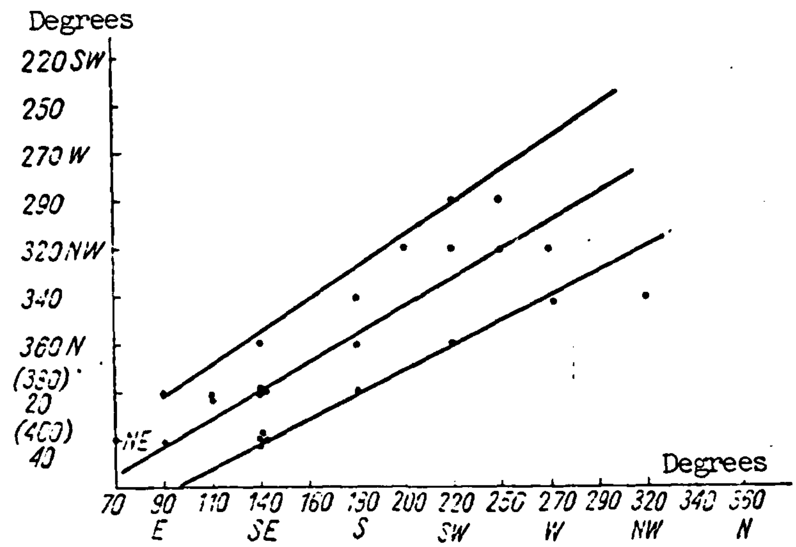

Figure 5a. The relation between the breeze direction and the direction of the land wind

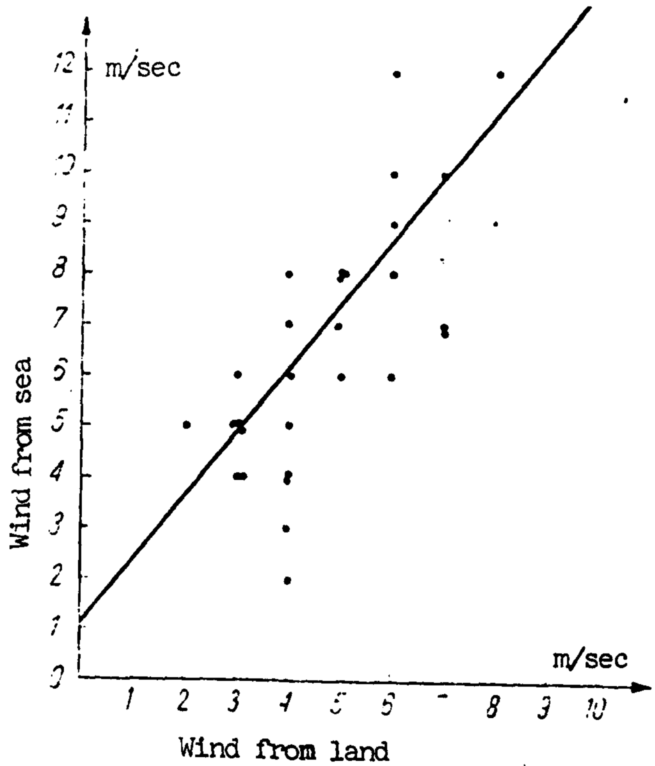

Figure 5b. The relation between the breeze speed and the speed of the land wind

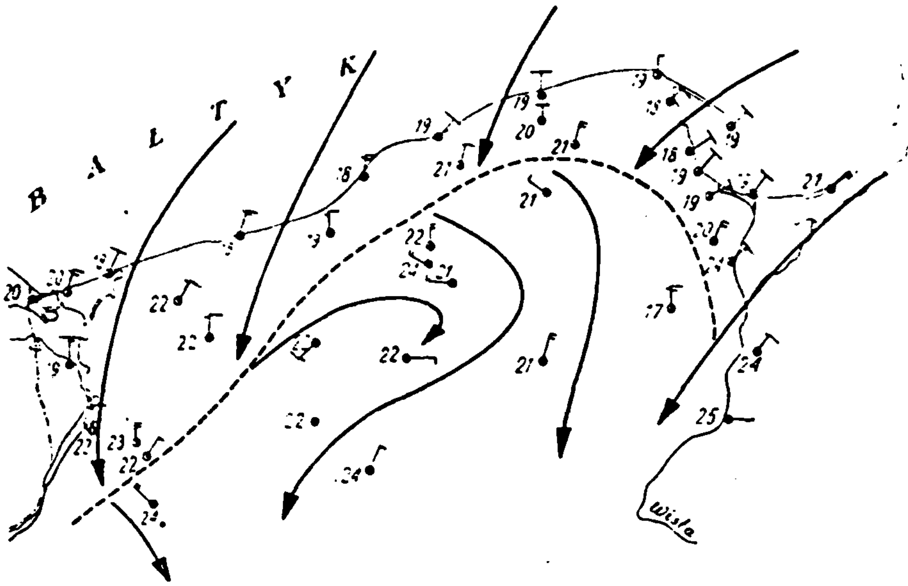

Figure 6. An example of the zone of the air currents with anti-cyclonic curvature before the breeze front on July 16, 1959

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Summary

The author examined the relation between the variation and reach of sea breezes on the Polish coast of Baltic Sea and synoptic situation paying regard to four typical situations. Maximal breeze reach, stated on charts, was 70 km in western part. The occurrence was stated in certain situations before the breeze front of the zone of anticyclonic curvature of stream lines, bound up, by the author, with descending motions of the air. There is a correlation between the direction and the speed of the breeze and of the land wind.

Figures

Fig. 1. An example of breeze on 30. V. 1959
a) distribution of air currents at 7^{00}
b) ,, ,, ,, ,, ,, 13^{00}
c) ,, ,, ,, ,, ,, 21^{00}

Fig. 2. An example of breeze on 24. VI. 1958
a) distribution of air currents at 7^{00}
b) ,, ,, ,, ,, ,, 13^{00}
c) ,, ,, ,, ,, ,, 21^{00}

Fig. 3. An example of breeze on 10. V. 1959
a) distribution of air currents at 7^{00}
b) ,, ,, ,, ,, ,, 13^{00}
c) ,, ,, ,, ,, ,, 21^{00}

Fig. 4. An example of breeze on 16. VI. 1958
a) distribution of air currents at 7^{00}
b) ,, ,, ,, ,, ,, 13^{00}
c) ,, ,, ,, ,, 21^{00}

Fig. 5a. The relation between the breeze direction and the direction of the land wind

Fig. 5b. The relation between the breeze speed and the speed of the land wind

Fig. 6. An example of the zone of the air currents with anticyclonic curvature before the breeze front on 16. VII. 1959.

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